

PROJECTION DISPLAY SYSTEMS  
FOR LIGHT VALVES

BACKGROUND OF THE INVENTION

5       The present invention relates to projection display systems for light valves such as liquid crystal display panels, and in particular to the use of color component rotators, such as retardation filters, to provide for improved projection display architectures.

10      Projection systems for reflective liquid crystal displays (LCDs) are generally characterized by their complexity and large size relative to the systems implemented for transmissive LCDs. FIG. 1A discloses a prior art configuration for a transmissive LCD projector, 15 while FIG. 1B shows a prior art reflective LCD projector for comparison. Dichroic filters DF1 and DF2 separate the red, green, and blue color components. The reflective LCDs require a polarizing beamsplitter (PBS) to be placed in front of each LCD in order to reflect 20 light toward the reflective LCD, and then to transmit the modulated light. These components add complexity to the system and require the use of a larger distribution and recombination optical system to divide the light into the three color channels (i.e. the optical paths traveled by 25 the three color components such as red, green and blue).

An alternative system for reflective LCDs divides the illumination into the three color channels and recombines the output distributions in a smaller and less complex system. The basic configuration is shown in 30 FIG. 2. However, the illumination input to this system must have a very specific distribution of color components and polarizations in which two of the color components (green and blue) are polarized in one direction, and the other color component (red) is 35 polarized orthogonally to the other two. In order to produce that combination of color components and polarizations, a complicated prefiltering system is

needed. One such system is shown in FIG. 2, and indicates that considerable complexity is added back to the system in order to implement the prefiltering. In the system shown in FIG. 2, only one half of the light is used, since the unwanted polarization state of each color component is simply discarded. In order to increase brightness of the system, a more complex prefiltering system is required that recycles the polarized light.

Various architectures have been proposed for projection display systems. Ledebuhr, U.S. Patent No. 4,687,301 and Ledebuhr, U.S. Patent No. 4,836,649 both describe projection systems for liquid crystal light valve (LCLV). The LCLV is an optically addressed reflective LC modulator and the systems described in these patents show optics to split a light source into separate colors paths and then individually illuminate and project the three LCLV devices. Both of these systems use only one-half of the illumination light since the unwanted polarization state is initially discarded. Ledebuhr, U.S. Patent No. 4,687,301 uses a complicated color separating system to direct the color components to the LCLVs. Ledebuhr, U.S. Patent No. 4,836,649 uses simpler but more numerous elements resulting in a large projection system.

Doany, et al. U.S. Patent No. 5,621,486 and Dove, U.S. Patent No. 5,658,060 both describe architectures that use Philips type prisms to control the three separate color channels. Doany, et al. U.S. Patent No. 5,621,486 uses a single PBS prism to control the light into and off of all three LCDs and a Philips prism to both split up and recombine the color channels. This arrangement appears simple, but the control of color in a Philips prism for p-polarization on the input and s-polarization on the output is extremely difficult and no successful implementation of this type of system exists. Dove, U.S. Patent No. 5,658,060 places a PBS prism in front of each LCD and uses the Philips prism only to

recombine the color channels. This requires a second optical arrangement to split up the color distributions and leads to a larger more complicated system overall.

Ooi et al., U.S. Patent No. 5,648,860 uses an offset illumination and projection scheme. The system does not use a PBS prism, but instead relies on the offset to separate the input and output light distributions. The color splitting and recombination is accomplished by tilted dichroics that perform essentially the same as the dichroics in a Philips prism, with the same polarization related problems.

Hattori et al., U.S. Patent No. 5,798,819 and Ueda U.S. Patent No. 5,918,961 both describe minor variations of the typical reflective LCD projector of FIG. 1B. These systems use a crossed dichroic prism to recombine light from the three LCDs and a separate crossed dichroic arrangement to perform the color splitting from the illumination system.

Sharp, U.S. Patent No. 5,751,384 describes techniques for making waveband specific retardation filters. This patent also describes a single panel LCD projector using the retardation filters in an active color shutter to gate the three colors onto the LCD for color field sequential projection.

Nevertheless, there still remains a need for a bright projection display system, preferably for reflective LCD panels, that utilizes a small architecture. What is therefore desired is a projection display that is as small or smaller than conventional projection displays, is capable of utilizing reflective LCD panels, uses readily available optical elements that perform well, uses conventional polarization converters, and provides good contrast without sacrificing brightness.

## BRIEF SUMMARY OF THE INVENTION

The present invention overcomes the drawbacks of the prior art by providing in a first aspect of the invention a projection display system having a light source, a polarization converter, at least one polarizing beamsplitter, at least one liquid crystal display panel for generating an image, a projection source for projecting the image, and a color component rotator located between the polarization converter and the projection source.

In a second separate aspect of the invention, a projection display system has a light source, a polarization converter, at least two polarizing beamsplitters, at least three liquid crystal display panels, each for generating a respective image, a projection source for projecting the images, and at least two color component rotators, each of the color component rotators located between the polarization converter and the projection source.

In a third separate aspect of the invention, a method of displaying an image is provided. First, light comprised of at least a first, second and third color component is provided. The light is converted to polarized light having a single polarization state. The first color component is separated from the second and third color components. The polarization state of the second color component is changed relative to the third color component. The second color component is separated from the third color component. Respective images are generated from each of the three color components. The images are then combined and projected.

The various aspects of the present invention each have one or more of the following advantages. The systems achieve their advantages through the use of color component rotators, or wavelength specific retardation filters, located within the optical systems to control the polarization orientation of one of the color

components in the system relative to the other two.. The use of a color component rotator allows the polarization orientation of the three color components to be controlled within the main color distribution and 5 recombination portion of the system rather than in a prefILTERING system included within the illumination optics. This allows the use of conventional polarization converters rather than complicated prefILTERing systems.

In addition, the use of color component 10 rotators enables smaller distribution and recombination systems than conventional reflective projection display systems, and in one case, smaller even than typical transmissive projection display systems. Thus, the 15 projection display systems and methods of the present invention reduce the overall projection display system size and complexity. The systems provide these advantages while achieving good contrast and without sacrificing brightness.

The foregoing and other features and advantages 20 of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

25 BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. 1A is a schematic diagram of a prior art transmissive LCD projector.

FIG. 1B is a schematic diagram of a prior art reflective LCD projector.

30 FIG. 2 is a schematic diagram of a projection display system that utilizes a prefILTERing system.

FIG. 3 is a schematic diagram of one embodiment of a projection display system of the present invention.

35 FIG. 4A is a second embodiment of a projection display system of the present invention.

FIG. 4B is a detail view of the distribution and recombination portion of the display of FIG. 4A.

FIG. 5 is a third embodiment of a projection display system of the present invention.

FIG. 6 is a fourth embodiment of a projection display system of the present invention.

5

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the figures, wherein like numerals refer to like elements, FIG. 3 shows an exemplary projection display 10 having an illumination portion 11 and distribution and recombination portion 22. Distribution and recombination portion 22 includes three reflective liquid crystal display (LCD) panels 14, 16, and 18, also referred to as liquid crystal light valves.

Illumination portion 11 includes a light source 12 for producing white light, which may be separated into different color components of different bandwidths, such as a red color component, blue color component and green color component. The white light from light source 12 passes through a polarization converter shown generally at 20. Polarization converter 20 may take the form of any conventional polarization converter, so that the randomly polarized light from light source 12 is converted into a single polarization state. In the embodiment shown in FIG. 3, the polarization converter 20 converts the white light from randomly polarized light into light that is polarized in the S direction.

Polarization converter 20 is a conventional polarization converter structure comprised of fly's eye lens plates 24, 26 and polarization converter prism array 28. Other polarization converters may also be used. While not preferred, the present invention could be used with a polarizing filter to produce uniformly polarized light; however, only half the light from light source 12 would be used. The polarized light is directed from the polarization converter 20 toward a mirror 30, which reflects the light through a lens 32.

DRAFT DRAFT DRAFT DRAFT DRAFT

The now S polarized light exits the illumination portion 11 of the display 10 and enters the distribution and recombination portion 22. The white light encounters dichroic filter 34, which separates the red color component from the blue and green color components. In general, dichroic filters transmit light of a certain bandwidth, and reflect light of another bandwidth. In display 10, dichroic filter 34 transmits the red color component while reflecting the blue and green color components.

Referring now to the blue and green channels, after reflecting from dichroic filter 34 the blue and green light components pass through a field lens 36, which in combination with other elements controls the size of the light projected on the LCD panel. The blue and green color components then pass through a polarizer 38 that transmits only S polarized light. The polarizer 38 improves contrast by filtering out P polarized light that otherwise may leak through to the LCD panels 16 and 18.

The blue and green color components then pass through a selective color component rotator 40, which rotates one of the color components (e.g., the blue color component) from one polarization state (e.g., the S polarization state) to another polarization state (e.g., the P polarization state). The color component rotator is a waveband specific retardation filter. It is a specially designed stack of retardation films in which the amount of retardation imparted to different wavebands can be selectively controlled by the orientation and number of retardation films used. The details of the design and operation of such color component rotators are described in Sharp, U.S. Patent No. 5,751,384. A retardation filter can be made to act like a half waveplate for one bandwidth of light while leaving light of all other colors or bandwidths unaffected. Such color component rotators may be obtained from Color Link in

Boulder, Colorado, or Cambridge Research & Instrumentation in Cambridge, Massachusetts. In the projection display 10, color component rotator 40 acts as a half waveplate for the blue color component, thus  
5 rotating the blue color component 90°, but leaving the green color component unaffected. Accordingly, the color component rotator 40 rotates the blue color component from the S to P polarization state, while the green color component remains in the S polarization state.  
10 The blue and green color components then enter a polarizing beamsplitter 41 having different polarization states (e.g., S and P, respectively). The polarizing beamsplitter reflects the S polarized green color component while transmitting the P polarized blue  
15 color component. The green color component reflecting off of the polarizing beamsplitter 41 is imaged using green LCD panel 16. The green image reflected by the modulated LCD panel 16 is in the P polarization state and is transmitted through polarizing beamsplitter 41 and  
20 into the crossed dichroic prism 42.

Returning to the blue channel, the blue color component transmitted through the polarizing beamsplitter 41 is transmitted through relay lens 44, reflected off of mirror 46 and transmitted through a second relay lens 48.  
25 The blue color component passes through another selective color component rotator 50, which rotates the polarization of the blue color component back to the S polarization state. The now S polarized blue color component then passes through a polarizer 51 which  
30 transmits S polarized light. The S polarized blue color component then enters a third polarizing beamsplitter 52, which reflects the S polarized blue color component onto the blue LCD panel 18. The blue image reflected by blue LCD panel 18 is in the P polarization state and is  
35 transmitted through polarizing beamsplitter 52 into the crossed dichroic prism 42. The relay lenses 44 and 48

are used to compensate for the longer path length of the blue channel relative to the green and red channels.

Returning to the red channel, the red color component is transmitted by dichroic filter 34 and is focused by a field lens 54. The red color component then passes through polarizer 56, which is oriented to transmit S polarized light. The polarizer 56 improves contrast by eliminating P polarized light that might otherwise leak through to LCD panel 14. The red color component then enters polarizing beamsplitter 58 which reflects the S polarized light into the red LCD panel 14. The modulated LCD panel 14 generates a red image. The reflected red image (in the P polarization state) passes through the beamsplitter 58 and into the crossed dichroic prism 42.

The three color components reflected from the three LCD panels 14, 16 and 18 pass through their respective polarizing beamsplitters and into the crossed dichroic prism 42, which combines the reflected images. The projection lens 62 then projects the converged images from all three LCD panels onto a projection screen (not shown).

The projection system of FIG. 3 retains the configuration of polarizing beamsplitters and crossed dichroic prism of the conventional reflective LCD projector shown in FIG. 1B. However, this projector significantly reduces the size of the optics required to distribute the illumination light into the three color channels. The key to this reduction is the use of the color component rotator 40, in this case a blue color component rotator, which allows the single polarizing beamsplitter 41 to perform the dual function of separating the green and blue color components and also to control the operation of green LCD panel 16. Thus the system 10 has significantly reduced the size and complexity of the optics required.

An alternative projection display system 10A is shown in FIGS. 4A and 4B. Like system 10 shown in FIG. 3, system 10A shown in FIG. 4A has a light source 12, red LCD panel 14, green LCD panel 16 and blue LCD panel 18.

5 The system 10A utilizes the same illumination portion 11. A polarization converter 20 comprised of fly's eye lens plates 24, 26 and prism array 28 provide light consisting of all three color components polarized in the S direction. Mirror 30 reflects light through lens 32 into

10 the distribution and recombination portion 22A of the system.

Referring now to the distribution and recombination portion 22A shown in more detail in FIG. 4B, dichroic filter 134 separates the white light by

15 transmitting the green color component while reflecting the red and blue color components. Referring to the green channel, the green color component passes through polarizer 156 which transmits light polarized in the S direction. The green color component then enters

20 polarizing beamsplitter 158 which reflects the S polarized light onto the green LCD panel 16. The reflected image (now in the P polarization state) passes through the beamsplitter 158 and through analyzer 160, which transmits light in the P polarization state.

25 Analyzer 160 improves contrast by eliminating S polarized light that has leaked through the green channel. The green color component is then reflected by dichroic filter 164, and then transmitted through projection lens 62.

30 Turning to the red and blue channels, the red and blue color components are reflected by dichroic filter 134 and passed through polarizer 136, which transmits only S polarized light. The red and blue color components then pass through a selective color component rotator 138, that acts as a half waveplate for the blue color component. Thus, the blue color component is rotated from the S polarization state to the P

polarization state, while the red color component remains unaffected. Thus, the two color components (red and blue) entering the polarizing beamsplitter 140 have different polarization states (e.g. S and P  
5 respectively). The polarizing beamsplitter 140 reflects the red color component and transmits the blue color component. The polarizing beamsplitter 140 reflects the S polarized red color component onto the modulated red LCD panel 14, which generates a red image now in the P  
10 polarization state. Similarly, the blue color component transmitted by the polarizing beamsplitter 140 is reflected off of the modulated blue LCD panel 18, which generates a blue image in the S polarization state. The red image reflected by LCD panel 14 is transmitted  
15 through polarizing beamsplitter 140 while the blue image reflected by LCD panel 18 is reflected by the polarizing beamsplitter 140. Both the red and blue color components pass through another selective color component rotator 150, which selectively rotates the blue color component  
20 from the S to the P polarization state, so that the two color components again have the same polarization state. The red and blue color components then pass through an analyzer 152 which transmits only light that is P polarized. The blue and red color components then pass  
25 through dichroic filter 164, where they are combined with the green color component and projected through projection lens 62.

The analyzer 152 and the second selective color component rotator 150 are introduced to control a  
30 practical implementation problem that arises due to the non-ideal operation of the polarizing beamsplitter 140. Ideally, a polarizing beamsplitter will reflect all S polarized light that enters and transmit all P polarized light. However, a typical practical polarizing  
35 beamsplitter has extremely high reflectivity for S polarized light with virtually no S polarized light transmitted. The transmitted light is therefore a highly

pure, P polarized distribution. However, the practical polarizing beamsplitter also reflects a small portion of the P polarized light, sometimes as much as 10 percent, giving a reflected distribution that is a mixture of 5 predominantly S polarized light and a small portion of P polarized light.

Turning now to the projection display system shown in FIG. 4B, the selective color component rotator 138 rotates the blue color component from the S to P polarization state, leaving the red color component S polarized. The light transmitted through polarizing beamsplitter 140 will be just the blue color component with the P polarization, but the reflected light will be the S polarized red color component and a small portion 15 of the P polarized blue color component. Accordingly, a portion of the blue color component leaks into the red channel and illuminates the red LCD panel 14. If the blue color component reflects off of the red LCD panel 14 without modulation, it will re-enter polarizing 20 beamsplitter 140 as P polarized light and transmit through the polarizing beamsplitter 140, through the dichroic filter 164, and through the projection lens 62. This undesired light will significantly reduce the contrast in the blue color component.

However, by introducing the second selective color component rotator 150, also designed like the color component rotator 138 to be a half waveplate for the blue color component, the unwanted P polarized blue color component from the red channel will be rotated to be S polarized. The desired output blue color component from 30 the blue channel will reflect out of the polarizing beamsplitter 140, as S polarized and will be rotated to the P polarization state by the selective color component rotator 150. The blue output distribution then has the same P polarized orientation as the desired red output 35 distribution. The analyzer 152, oriented in the P direction, transmits the desired red and blue color

DRAFT - 07/06/2000

components in the P polarization state, but absorbs and eliminates the unwanted blue color component in the P polarization state that leaked into the red channel and reflected off of the red LCD panel 14 through polarizing beamsplitter 140. Some portion of the blue color component that leaks into the red channel may be modulated by the red LCD panel 14 and re-enter the polarizing beamsplitter 140 as S polarized light. If this occurs, the polarizing beamsplitter 140 has strong S polarized reflection and virtually no S polarized transmittance. The modulated portion of the blue leakage color component will then be reflected back toward the illumination optics and will not pass through to the projection lens. This particular configuration of using two selective color component rotators 138, 150 and an analyzer 152 is essential to enable the high contrast operation of two LCD panels with a single PBS prism.

Another alternative projection display system is shown in FIG. 5. The system again begins with a conventional illumination system as described previously for the embodiments of FIGS. 3 and 4A and 4B. The input color components, all S polarized, enter the color distribution and recombination portion 22B of the system 10B. A green transmitting dichroic filter 134 reflects the blue and red color components up to the polarizing beamsplitter 140. The polarizer 136 and analyzer 152, the selective color component rotators 138 and 150, and the polarizing beamsplitter 140 control the operation of splitting and recombining the red and blue color components in exactly the same fashion as in the system 10A of FIGS. 4A and 4B.

The alternative arrangement is contained within the green channel. The S polarized green color component is passed through lens 200 and is reflected by mirror 202. The green color component then is passed through lens 204 and polarizer 206. The polarizer 206 removes any residual P polarized light. The green color

component then passes through a selective color component rotator 208, which is designed and oriented to rotate green light polarization by 90 degrees, so as to rotate the green color component to the P polarization state.

5      The green color component passes through polarizing beamsplitter 216 to the green LCD panel 16. The relay lenses 200 and 204 are used to compensate for the longer path length of the green channel relative to the red or blue channels. A block of glass 212 is introduced to

10     provide the same optical path length for the green channel as the red and blue channels between the LCD panels and the projection lens. The modulated LCD panel 16 generates a green image, which is reflected in the S polarization state. The green image reflects off of the

15     polarizing beamsplitter 216 and into a color component rotator 210. This color component rotator 210 selectively rotates the polarization of the green color component from the S to the P state. The analyzer 214 eliminates any green light that might have been reflected

20     into the red or blue channel from polarizing beamsplitter 216 and maintains high contrast performance for the green channel.

While exemplary projection displays have been described, other projection display configurations that utilize LCD panels (either reflective, transmissive or a combination thereof) and polarizing devices such as polarization converters may find utility with the present invention. Moreover, other color components, wavelength ranges, and polarization states may be used as desired.

30     Other alternative system architectures are also possible. In the system shown in FIG. 4B, dichroic filter 134 may instead transmit the red or blue color component. Alternatively, the output dichroic filter 164 could be changed to a green transmitting filter 164A rather than a green reflecting filter. The resulting system configuration is shown in FIG. 6. The projection lens 62 is moved to capture the output and send the

projected image up rather than to the right, and may be considered for overall system packaging considerations.

With respect to the embodiment shown in FIG. 3, it may be possible to switch the red reflecting dichroic 5 in the crossed dichroic prism 42 to a green reflecting dichroic. Then by changing the input dichroic filter 34 to a green transmitting filter, the LCD panels 14 and 16 may be substituted for each other, so that the green color component would enter from the bottom as shown in 10 FIG. 3 while the red color component would enter the crossed dichroic prism 42 from the left as shown in FIG. 3.

The terms and expressions which have been employed in the foregoing specification are used therein 15 as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding equivalents of the features shown and described or portions thereof, it being recognized that the scope of the invention is defined and 20 limited only by the claims which follow.